

Coronal Holes and High Speed Streams

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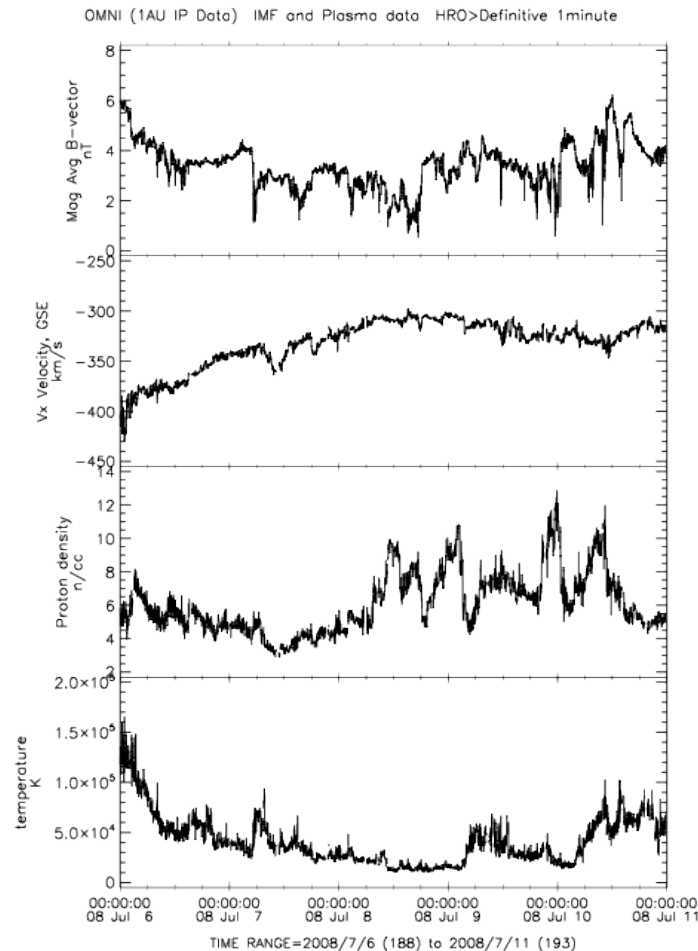
The **solar wind** is a flow of **plasma** and the frozen-in solar **magnetic field** from the Sun. The outward flow is due to the gas pressure difference between interplanetary space and the solar corona.

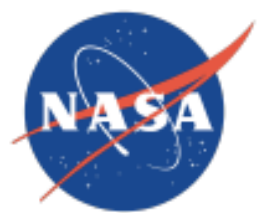
Changes in the solar magnetic field (from solar activity) influence the solar wind which, in turn, influences planets, spacecraft, and other bodies inside the solar wind (the **heliosphere**).

TABLE 4.1. Observed Properties of the Solar Wind near the Orbit of the Earth (1 AU)

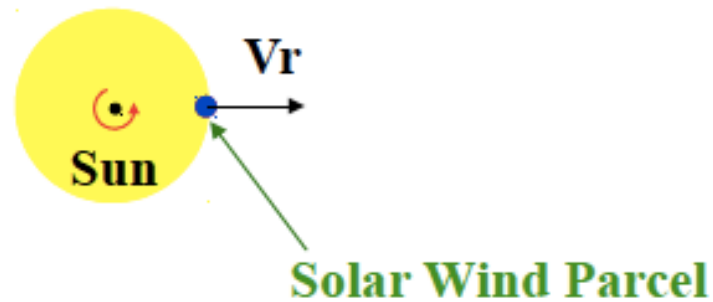
Proton density	6.6 cm^{-3}
Electron density	7.1 cm^{-3}
He ²⁺ density	0.25 cm^{-3}
Flow speed (nearly radial)	$450 \text{ km} \cdot \text{s}^{-1}$
Proton temperature	$1.2 \times 10^5 \text{ K}$
Electron temperature	$1.4 \times 10^5 \text{ K}$
Magnetic field (induction)	$7 \times 10^{-9} \text{ tesla (T)}$

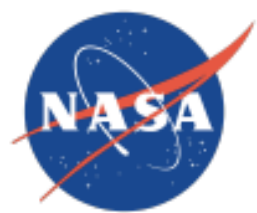
near the Earth, compared to the magnetosphere, the solar wind plasma (mostly ionized Hydrogen) is hot, tenuous, and fast moving, and the weak magnetic field is nearly parallel to the ecliptic plane, but 45° to the Sun-Earth line



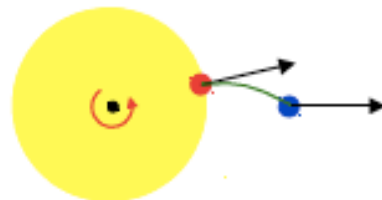


The Solar Wind and the Interplanetary Magnetic Field (Formation of the Parker Spiral)



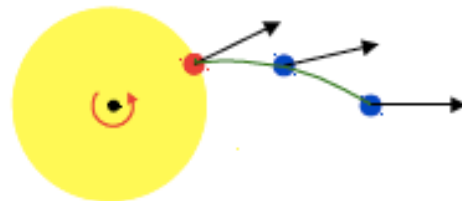


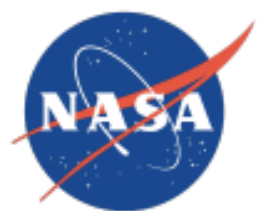
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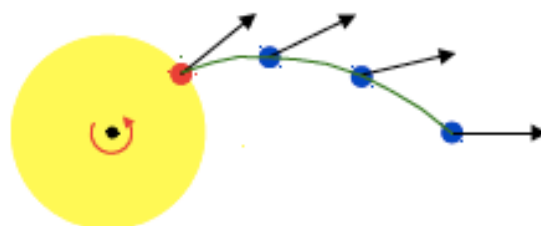


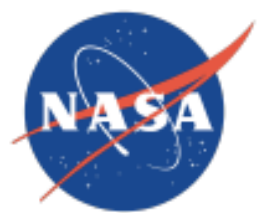
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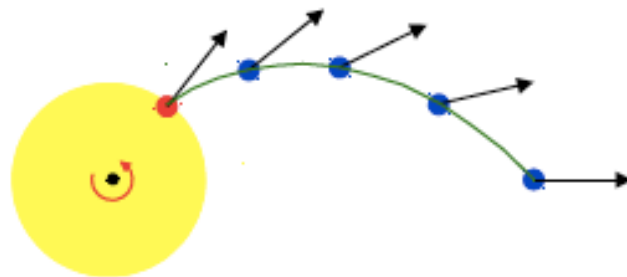


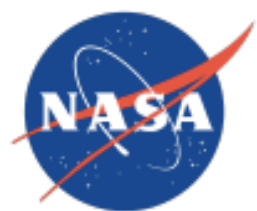
The Solar Wind and the Interplanetary Magnetic Field (Formation of the Parker Spiral)



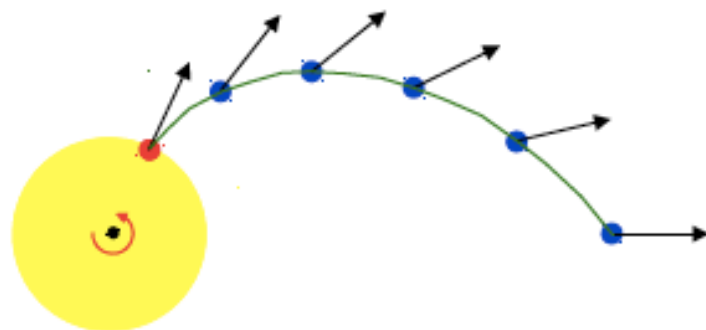


The Solar Wind and the Interplanetary Magnetic Field (Formation of the Parker Spiral)



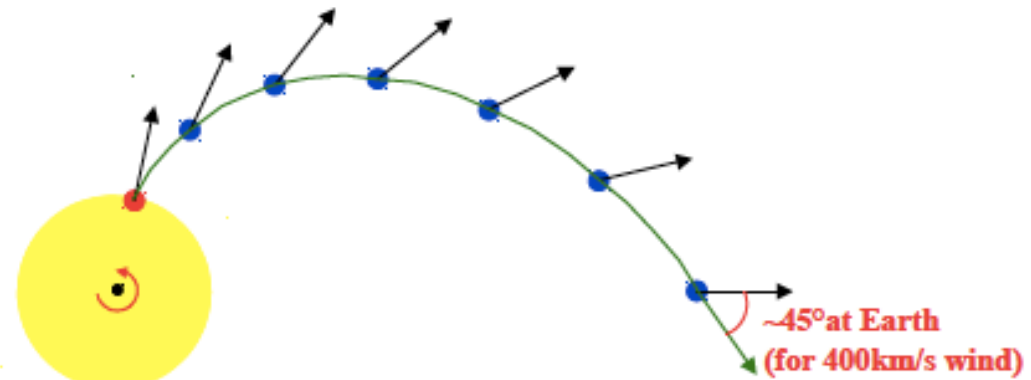


The Solar Wind and the Interplanetary Magnetic Field (Formation of the Parker Spiral)





The Solar Wind and the Interplanetary Magnetic Field (Formation of the Parker Spiral)



Magnetic Field Line

Because (1) the solar wind flows away from the Sun radially AND (2) the magnetic field and solar wind plasma flow together (i.e., frozen in flux condition), (some) magnetic field lines attached to the Sun are dragged out into space forming a spiral pattern called the **Parker Spiral**.

Sketch by C.N. Arge!

Due to solar **rotation** parcels of solar wind plasma leaving the sun form a spiral (analogous to the water spirals formed from a rotating sprinkler), which is called the **Parker spiral**. The angle that a solar wind magnetic field line makes at 1 AU is close to 45 degrees.

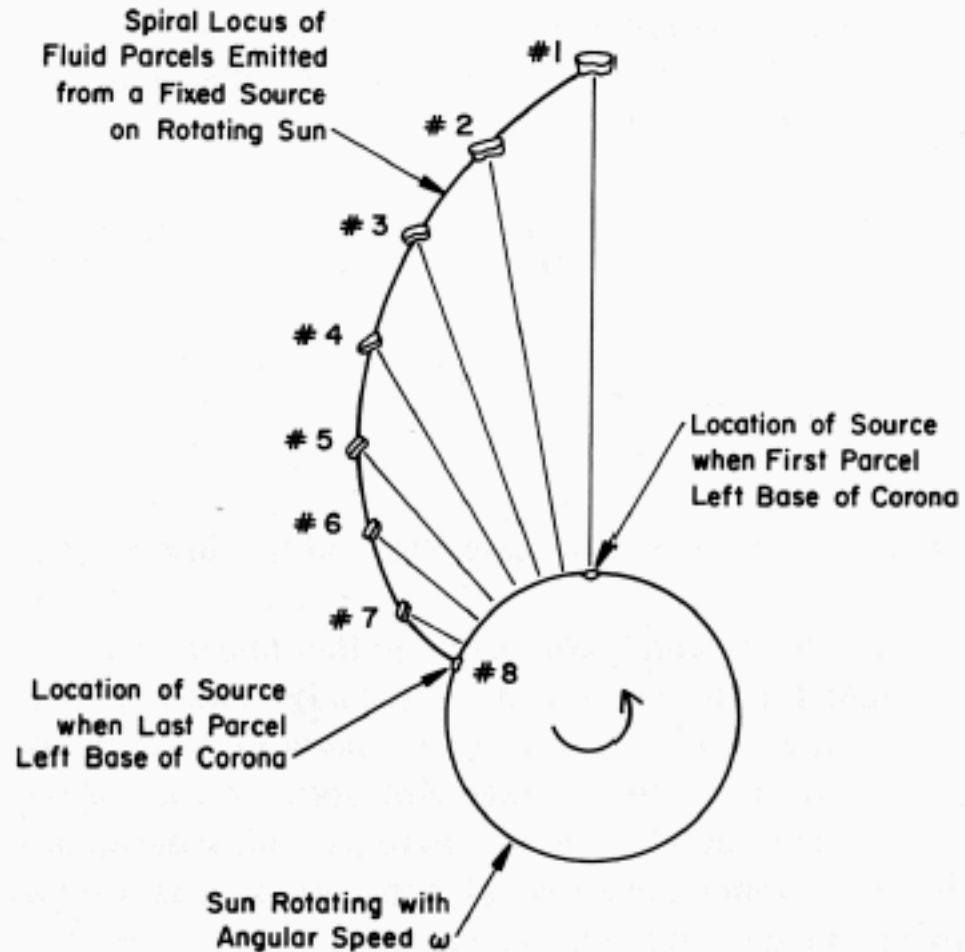


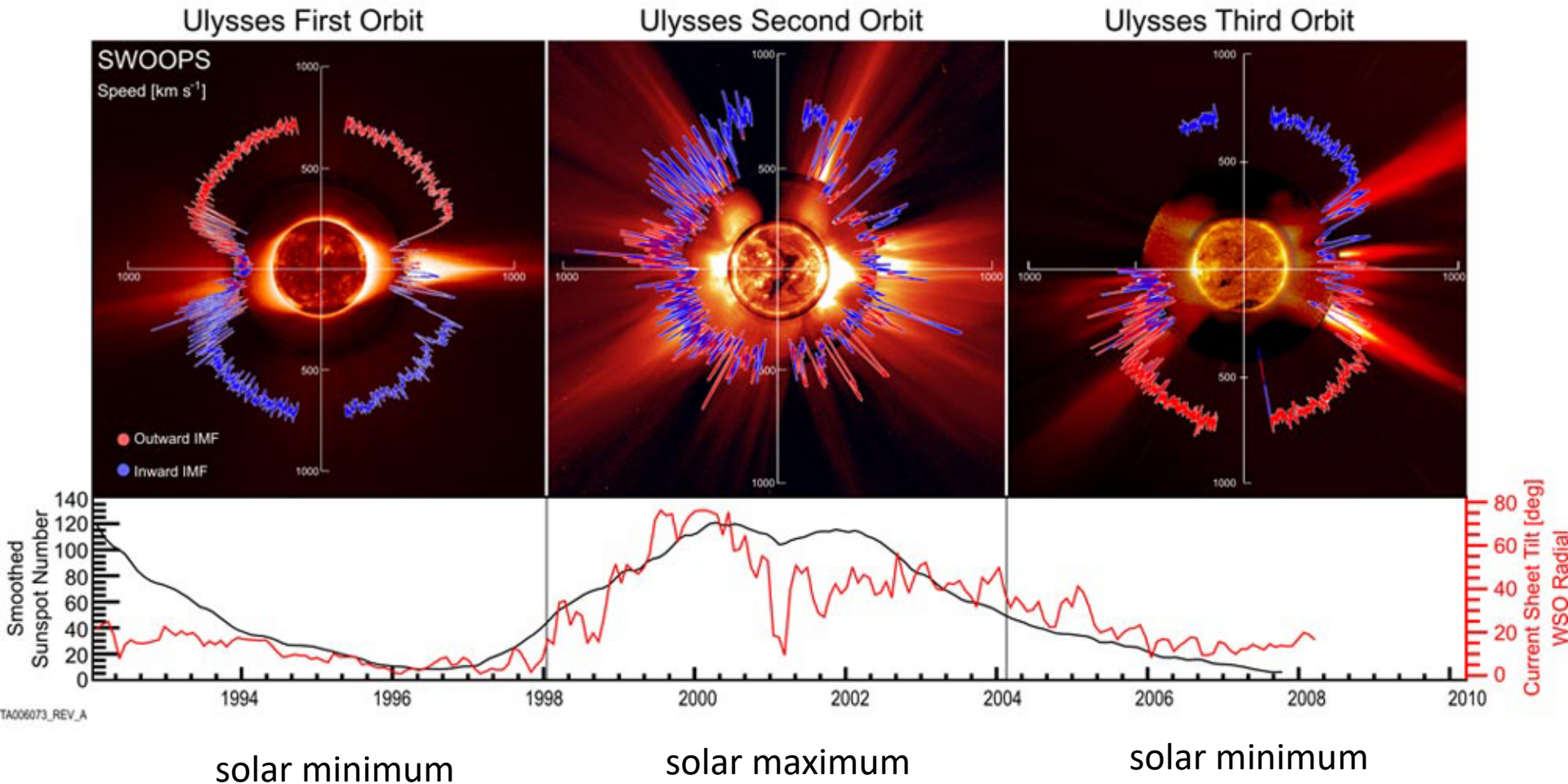
FIG. 4.5. Loci of a succession of fluid parcels (eight of them in this sketch) emitted at constant speed from a source fixed on the rotating sun.

Solar wind can be divided into fast and slow wind components.

Fast wind	Slow wind
450–800 km/s	<~450 km/s
$n_p \sim 3 \text{ cm}^{-3}$	$n_p \sim 7\text{--}10 \text{ cm}^{-3}$
~95% H, 5% He, minor ions and same number of electrons	~94% H, ~4% He, minor ions and same number of electrons – great variability
$T_p \sim 2 \times 10^5 \text{ K}$	$T_p \sim 4 \times 10^4 \text{ K}$
$B \sim 5 \text{ nT}$	$B \sim 4 \text{ nT}$
Alfvénic fluctuations	Density fluctuations
Origin in coronal holes	Origin ‘above’ coronal streamers and through small-scale transients

(Bothmer and Zhukov, 2007)

Solar wind can be divided into fast and slow wind components.



Large-scale structures in the solar atmosphere

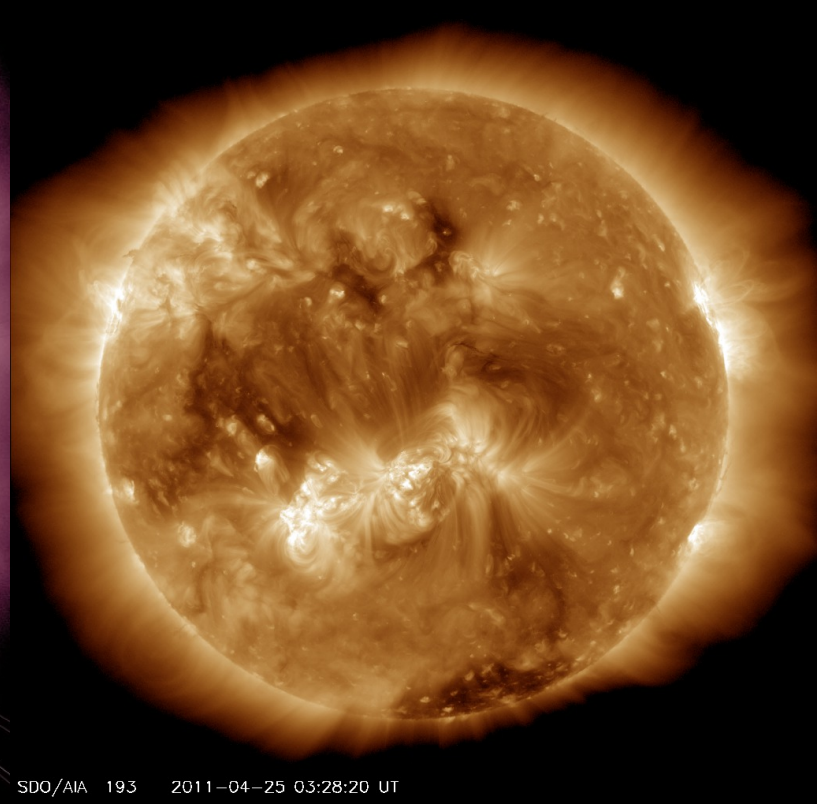
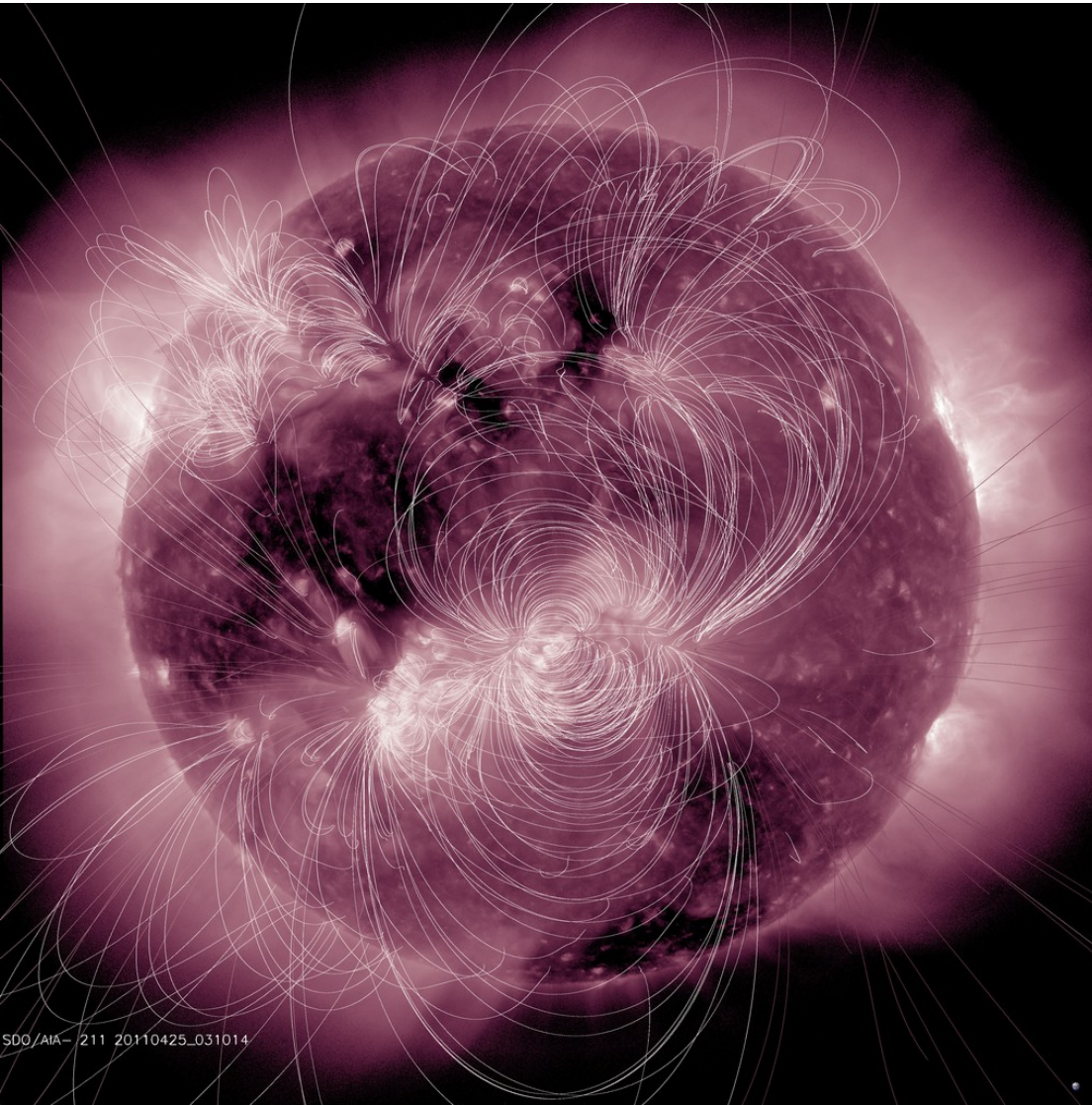
Large-scale structures in the solar atmosphere:

- Active regions (active region canopies)
- Filaments/prominences
- Coronal holes

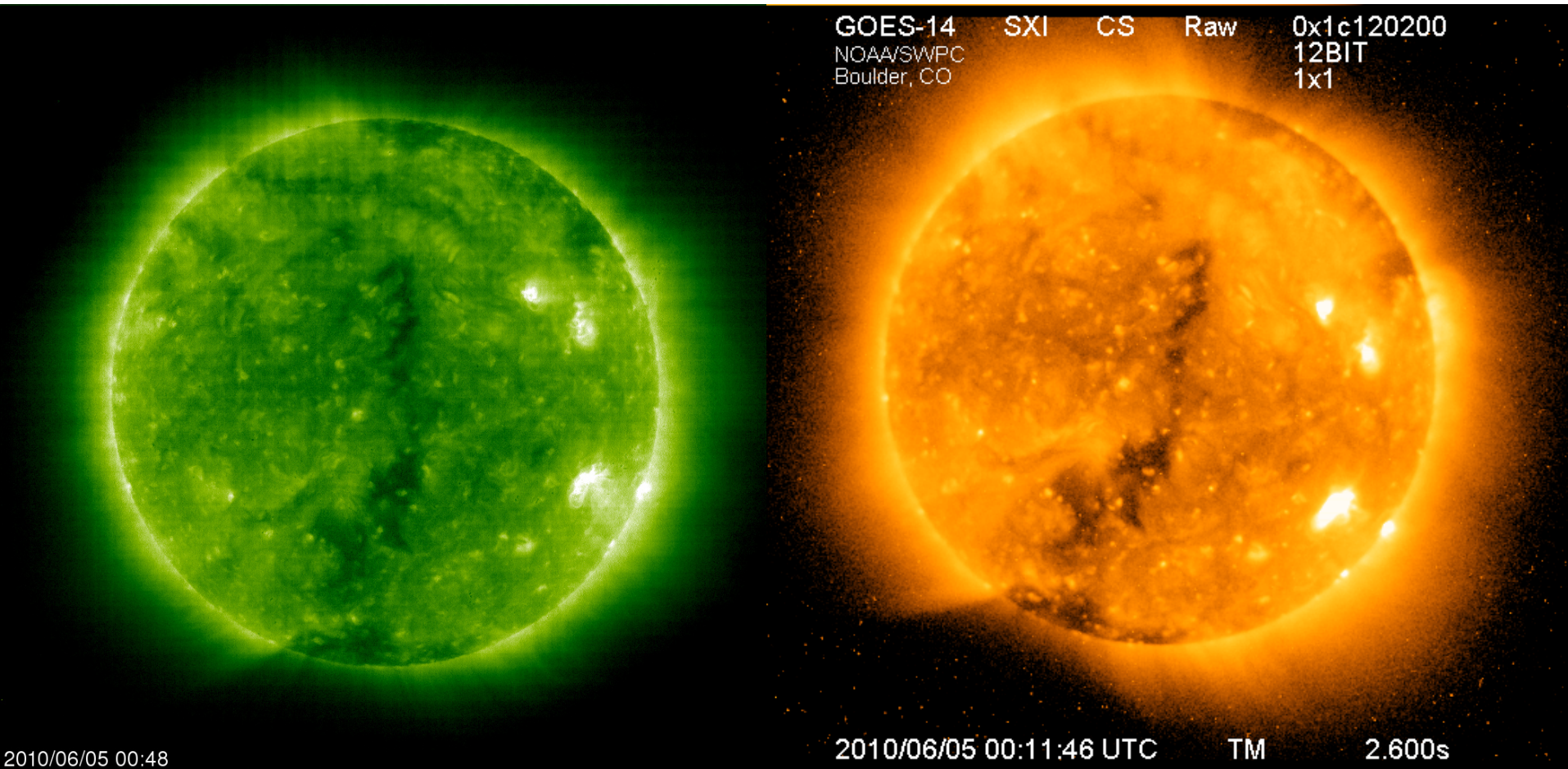
Large scale structures in the corona

- Images: SDO AIA 193 Å, STEREO EUVI 195 Å
(filter contains Fe XII 195 Å line, $T \sim 1.5$ MK)
- Line-of-sight magnetograms: polarity inversion line (PIL)
- **Active Regions:** bi-polar, bright (emission), closed magnetic field (field lines perpendicular to PIL)
- **Filaments:** bi-polar, dark (absorption), closed magnetic field (field lines parallel to PIL)
- **Coronal hole:** uni-polar, dark (less dense), open magnetic field

Coronal holes appear as dark areas on the solar surface in the **EUUV** (extreme ultraviolet) and **X-ray** radiation. They have a **lower density** and **temperature** compared to the surrounding corona. **Coronal holes** correspond to regions of open magnetic fields. Visible best in lines with temperatures more than 1.5 MK.



Large **polar coronal holes** are persistent for about 7 years around solar minimum. During solar maximum and high solar activity **coronal holes** exist at all latitudes, but are less persistent.



Coronal holes correspond to regions of open magnetic fields.

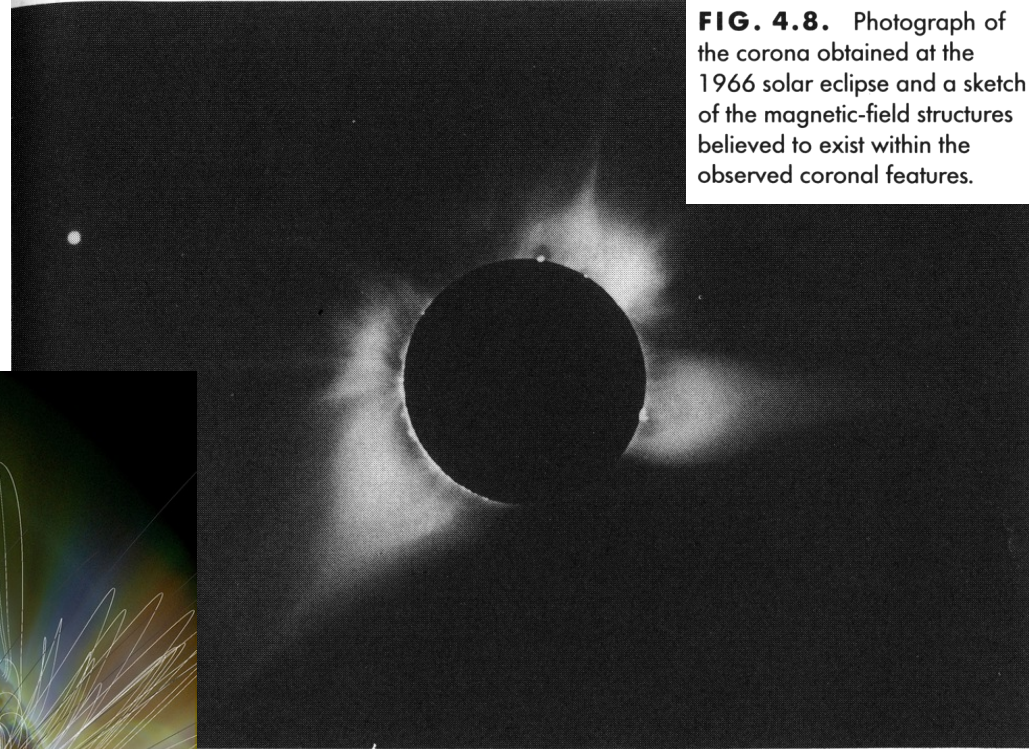
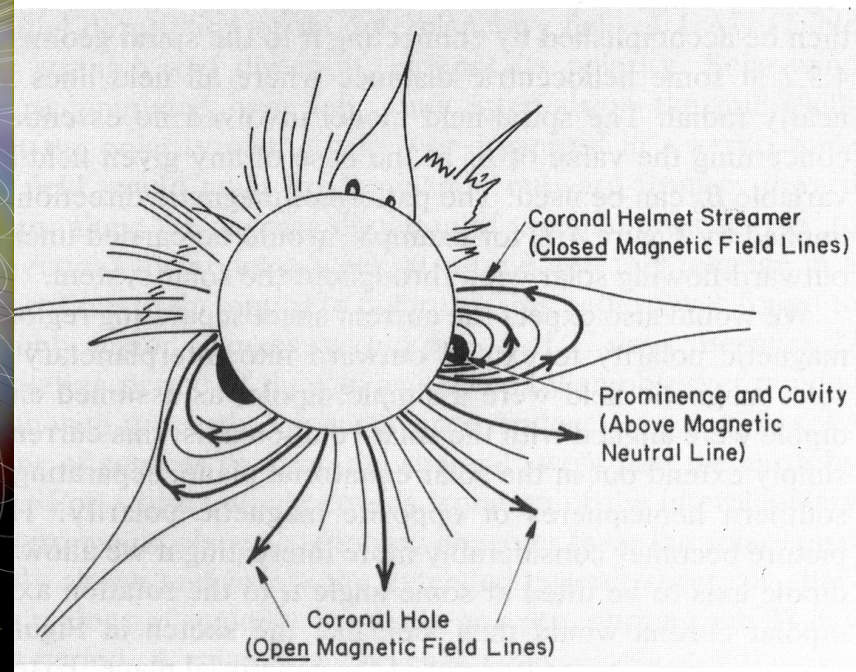
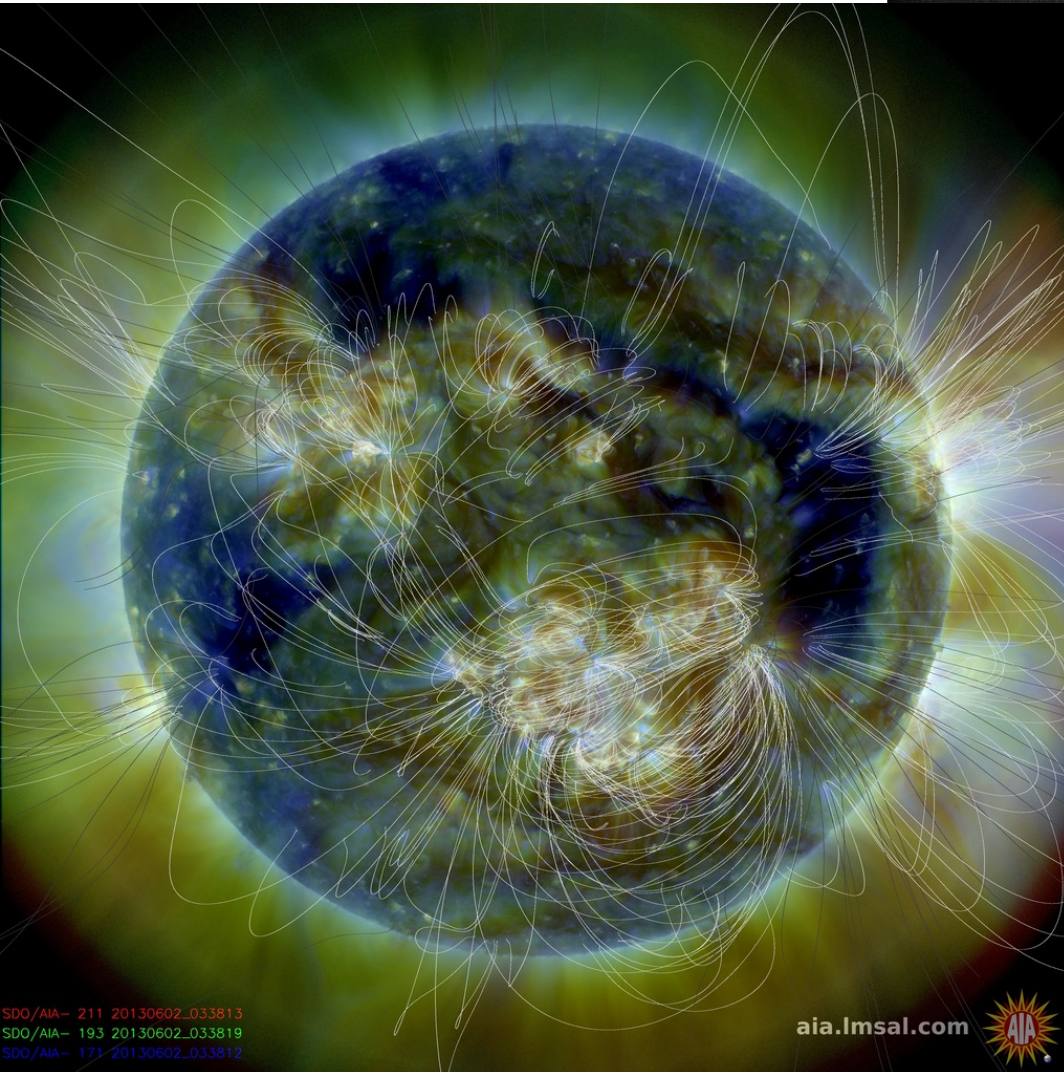


FIG. 4.8. Photograph of the corona obtained at the 1966 solar eclipse and a sketch of the magnetic-field structures believed to exist within the observed coronal features.



High speed solar wind streams are formed by higher speed solar wind originating from **coronal holes**. Higher speed streams are less tightly wound in the Parker spiral compared to slower ones, and at various distances the faster solar wind **overtakes** the slower wind ahead of it.

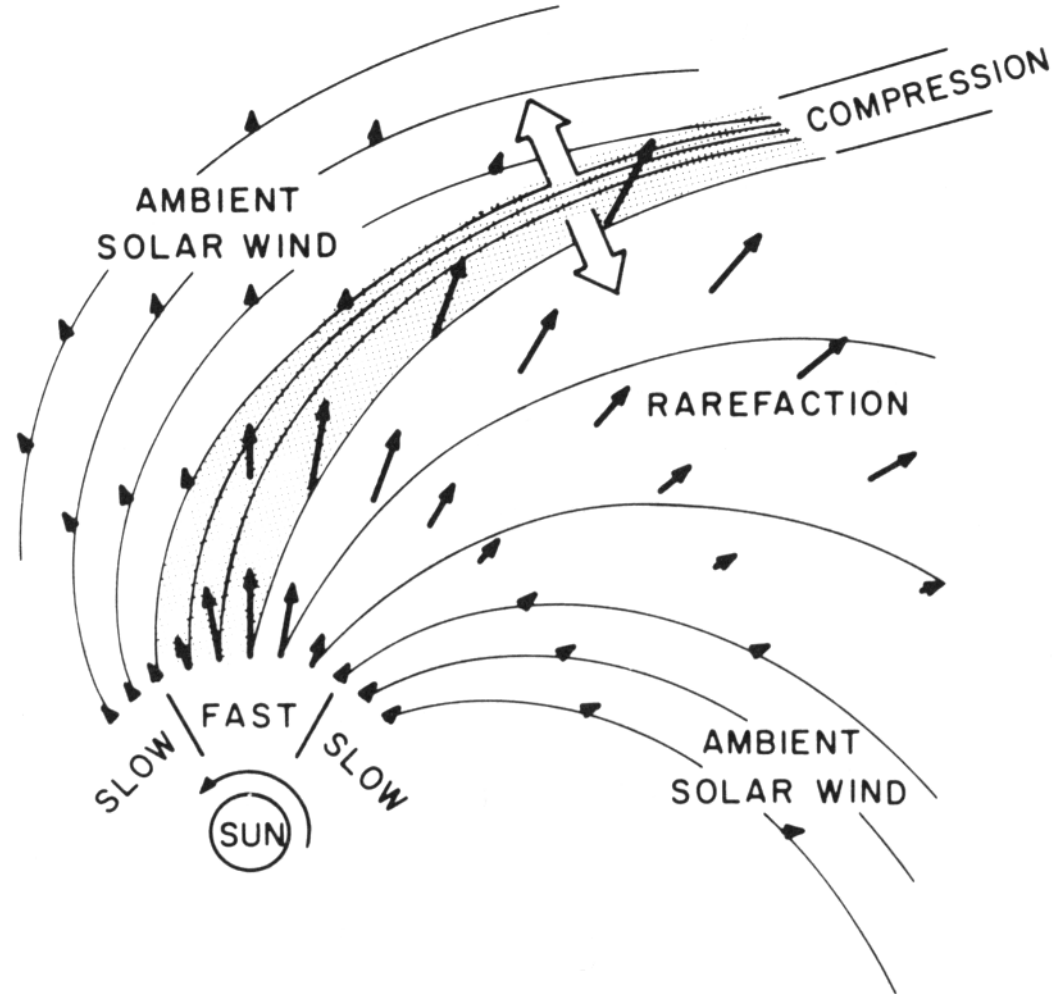


FIG. 4.13. Geometry of the interaction between fast solar wind (on less tightly wound spiral streamlines) and ambient solar wind (on more tightly wound spiral streamlines). The plasma is compressed where streamlines converge. (From Pizzo, 1985.)

A **stream interaction region** (SIR) forms at the compressed boundary between the fast and slow solar wind in a high speed stream. High speed streams from persistent coronal holes over multiple solar rotations are called **corotating interaction regions** (CIRs).

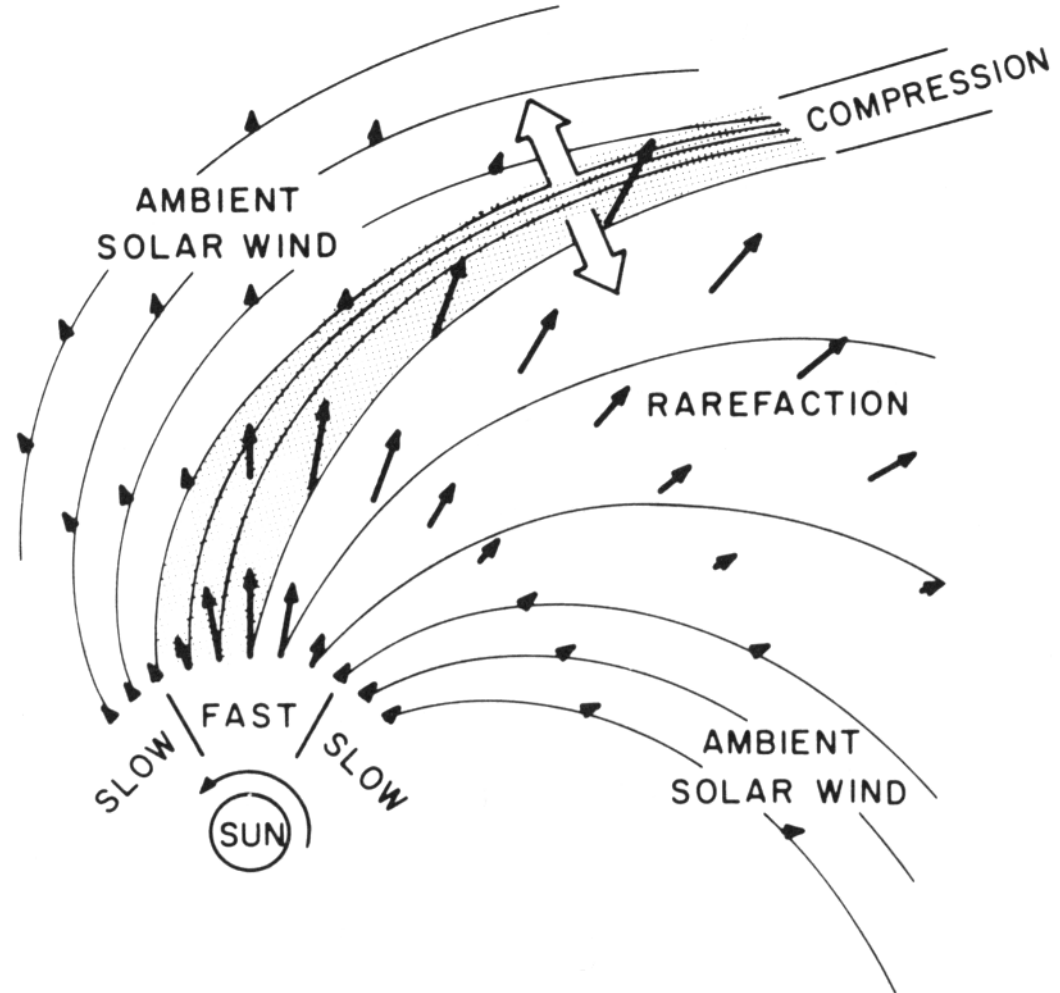
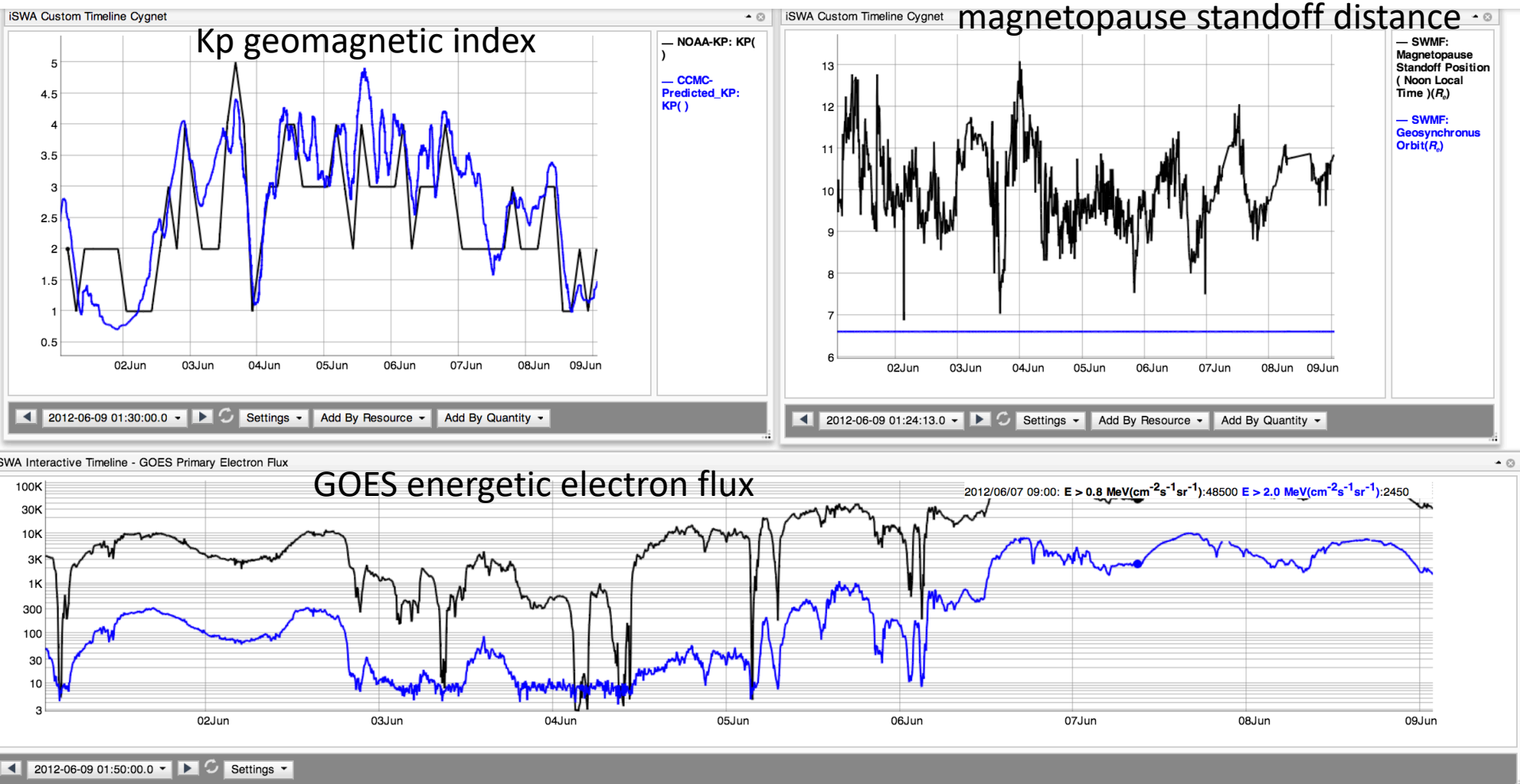


FIG. 4.13. Geometry of the interaction between fast solar wind (on less tightly wound spiral streamlines) and ambient solar wind (on more tightly wound spiral streamlines). The plasma is compressed where streamlines converge. (From Pizzo, 1985.)

A high speed stream can cause an energetic **electron flux enhancement** in the radiation belt.



The increase in speed from a solar wind high speed stream pumps energy into the magnetosphere which can cause **geomagnetic storms** and **energizes particles**.

They can produce energetic **electron flux enhancements** in the radiation belt.

Geomagnetic storms are disturbances/changes in Earth's magnetic field due to changes in solar wind conditions typically lasting 3-6 days.

High speed streams can also cause geomagnetic storms, however they are longer in duration and not as strong as geomagnetic storms caused by CMEs.

(the magnetosphere lesson will go into more detail)

Slide link summary

SW REDI website

<http://ccmc.gsfc.nasa.gov/support/SWREDI/swredi.php>

iSWA <http://iswa.gsfc.nasa.gov>

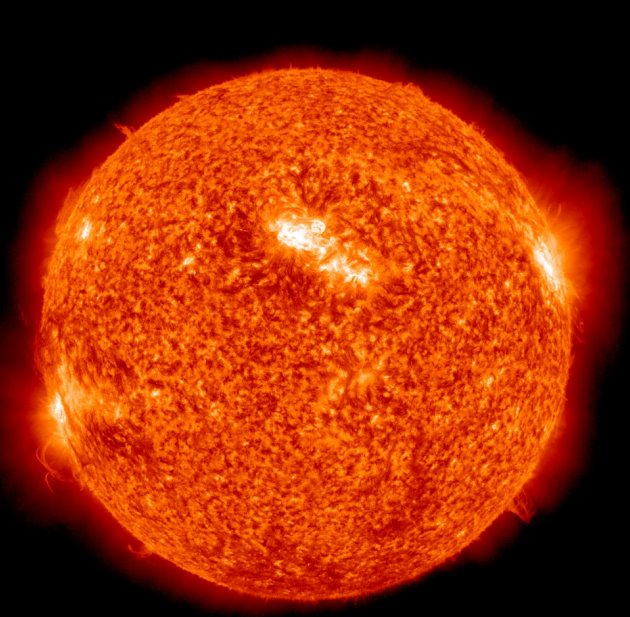
iSWA Cygnet Glossary http://iswa3.ccmc.gsfc.nasa.gov/wiki/index.php/Full_iSWA_Cygnet_List

iSWA Space Weather Glossary <http://iswa3.ccmc.gsfc.nasa.gov/wiki/index.php/Glossary>

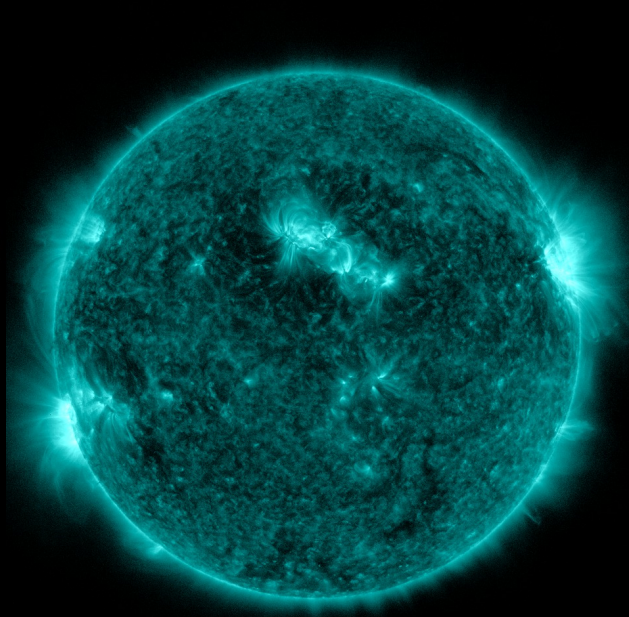
Most figures and tables in the slides are from the “Introduction to Space Physics” textbook

<http://www.cambridge.org/us/knowledge/isbn/item1145043>

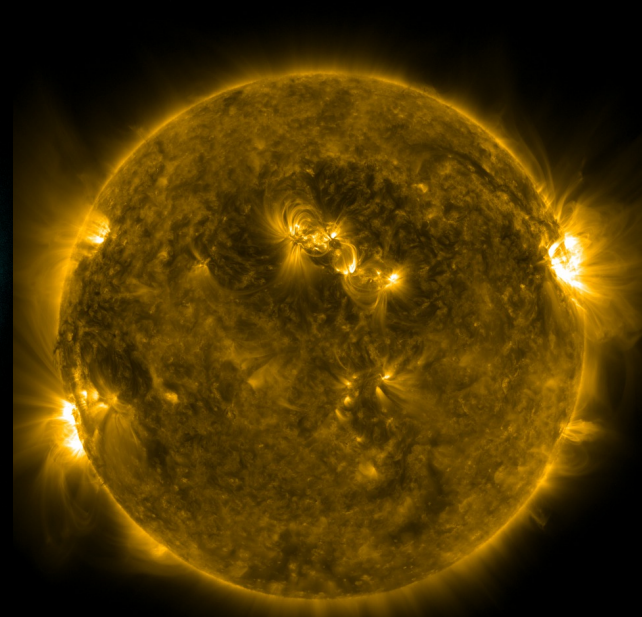
iSWA layout of a high speed stream observed at ACE <http://go.nasa.gov/17nkicp>



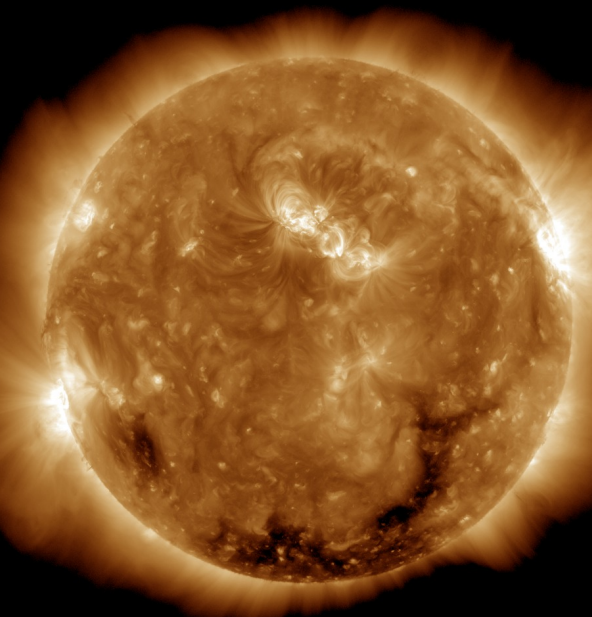
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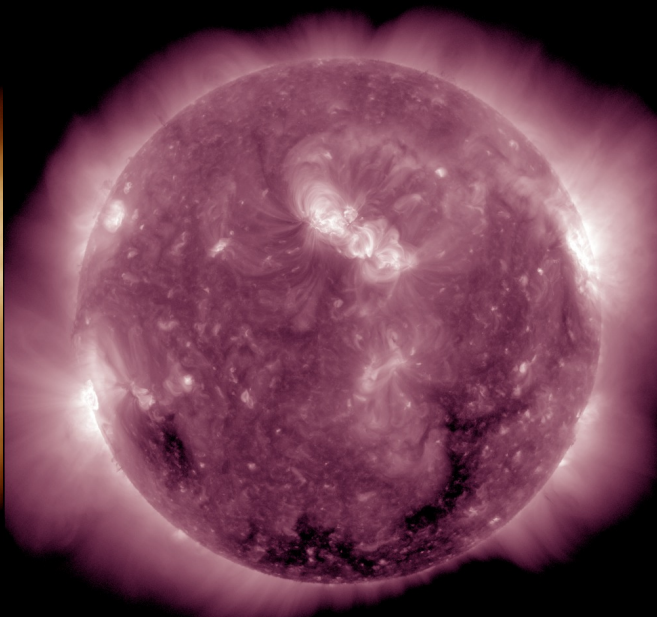
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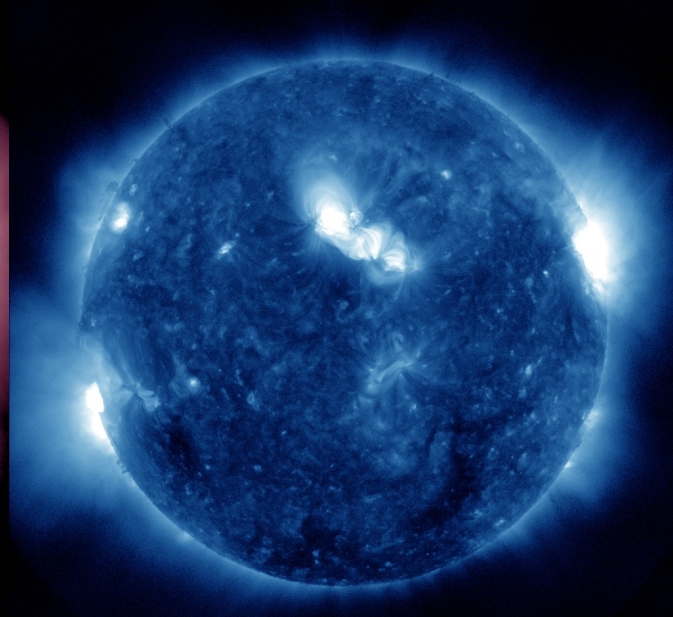
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O/AIA 193 2011-04-19 06:58:20 UT



SDO/AIA 211 2011-04-19 06:58:26 UT



SDO/AIA 335 2011-04-19 06:58:41 UT